THE INFLUENCE OF MAGNETISM ON LIGHT

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IT is not such a great while since the various subjects of light, heat, electricity and magnetism, embodied in the science of physics—or "natural philosophy" as it used to be called—were thought of as discrete branches only slightly interrelated. The task of showing the connection between them may be thought of as commenced by Oersted, who discovered, almost exactly a century ago, the effect of an electric current on a magnetic needle. Half a century later the theoretical work of Maxwell supplemented by the experiments of Hertz showed that light is, fundamentally, nothing but a particular manifestation of electrical and magnetic phenomena. But the discovery of the electron in recent times has done more than anything else to unify physics, and the division of the science into branches may be regarded henceforth merely as a separation for convenience in instruction rather than as a natural cleavage.

But while light is now well known to be an electromagnetic wave phenomenon, occupying indeed a position intermediate between the long electromagnetic vibrations or wireless waves, on the one hand, and the extremely short undulations which the X-rays have very recently been shown to be, on the other, the experimental study of the relationship is not simple. Nevertheless a whole series of investigations, initiated by Faraday's capital discovery of the rotation of the plane of polarization produced by a magnetic field, has been carried out in recent years with the aim of finding out the effect of magnetic and electrical influences on light.

The most striking result yielded so far is the effect, discovered in 1896 by Zeeman, of a powerful magnetic field on a source of light. This phenomenon, which is too minute to have been observed by Faraday, who tried the experiment, consists, in its simplest form, of the doubling or tripling of a spectral line according as the source is observed along the line of the magnetic field, or across it, respectively. On the basis of the electron theory the explanation may be outlined as follows: Suppose that in a small monochromatic source of light (*e. g.*, vacuum tube, flame, etc.) between the poles of a large electro-

magnet one of the countless electrons is rotating in a circular path about the axis of the field, giving rise as it does so to a light wave of period corresponding to its rotation. If, now, the magnet is excited there will be a force acting on this electron—just as there would be on a flexible circular wire carrying a current—which will tend to pull it into an orbit of smaller radius or push it out to a larger one according to the direction in which it is turning. The result will be exactly what would happen to a planet moving according to Kepler's laws: a diminution in orbit means a shorter time of revolution, and *vice versa*. Accordingly, when the field is excited all electrons rotating in one direction will suffer a shortening of their periods, while those turning oppositely will show a corresponding lengthening. Thus a single spectral line is split into a "doublet" whose components will, moreover, be found to be circularly polarized.

The obvious difficulty of this simple explanation arising from the fact that naturally only a very small proportion of the electrons would be found vibrating in circles oriented as presupposed, disappears when we remember that any vibratory motion is resolvable along three axial directions and that the simple harmonic vibrations along either of those perpendicular to the field is resolvable into the circular motions above described. The third vibration is in the line of the field and therefore not influenced by the magnet; hence when the phenomenon is viewed transversely there is a third component in the position of the original line.

It is hard to overestimate the importance of this discovery by Zeeman, leading as it has, on the one hand, to the brilliant researches of Hale and his co-workers on magnetic fields in the sun, and, on the other, to the explanation of many of the effects of magnetism on light.

Most of these effects have to do with polarized light and are allied to the Faraday rotation above mentioned. This experimenter established the fact that when plane polarized light traverses any transparent substance in a magnetic field—the direction being parallel to the lines of force—the plane of polarization suffers a rotation. The effect, which is analogous to that produced by a naturally active substance (*e. g.*, sugar solution), varies in amount with the character and thickness of the material, strength of field, wave-length of light and certain minor factors. Practical use has indeed been made of this well-known phenomenon in connection with a "massless" photographic shutter suitable for use in experiments on the photography of projectiles in flight. The light passes through a

nicol prism and is thereby polarized, so that when it reaches a second nicol "crossed" on the first no light is transmitted. Between the two is a tube of carbon bisulphide—a strongly magneto-optic substance—in a helix of wire. The passage of a momentary current magnetizes the helix and rotates the plane of polarization of the light passing through the carbon bisulphide sufficiently to permit the passage of a flash of light through the second nicol.

This effect, moreover, is not limited to transparent substances, for the magnetic metals, particularly iron, have enormous rotatory powers when specified in terms of a centimeter thickness. Indeed, if light could penetrate a centimeter into strongly magnetized iron it would suffer no less than five hundred complete revolutions of its plane of polarization, but the opacity of such substances is so great as to prevent the use of a film of thickness much greater than the ten-thousandth part of a millimeter, so the actual rotation is of the order of only a degree or two. Gases and vapors, especially of sodium, may also produce considerable rotations as shown by the extended experiments of Wood.

For the last dozen years, the writer has made a special study of this subject of rotatory polarization in its various phases. The rotation has been determined for a variety of substances as dependent on the wave-length of light used, not only for the visible, but also for a portion of the long wave, or infra-red, spectrum. The study has not been limited to transparent substances, but has also included the magnetic metals, particularly for the case of reflection (Kerr effect) for various directions of magnetization. Of late the work has been extended to include a comparison of the magnetic with the natural rotation, such as produced by a sugar solution, for a number of active substances. The experimental work has not been without its difficulties; for the eye must necessarily be supplanted by the bolometer when working with the infra-red radiations, and this, with its entailed accessories, makes up an apparatus rather complicated in comparison with the relatively simple arrangement that suffices for the study of rotatory polarization in the visible spectrum.

The results are naturally divided into two groups, according as they are for transparent substances or for the magnetic metals. The magnetic rotation of practically all representatives of the former class shows a rapid diminution with increasing wave-length as far as the writer has been able to investigate in the infra-red, that is, to a wave-length some three times

longer than any the eye can see. The rotation for wave-length 2μ (.002 mm.) is less than one tenth of what it is for sodium light. The dispersion curves for different substances are much alike and are in general quite similar to the natural rotation curves (for such of the substances as are naturally active) over the whole spectral region examined. The temperature coefficients of rotation are, however, quite different in some cases.

The metals present a more interesting, as well as more complicated, case than transparent substances. As Kerr showed, half a century ago, when polarized light is reflected from the polished surface of a highly magnetized steel mirror the plane of polarization suffers a slight rotation. This effect has been investigated by a number of observers for the visible spectrum and by the writer on the infra-red side. The rotation-dispersion in the visible spectrum is "anomalous," that is, the effect increases with longer wave-length instead of diminishing as does the rotation in transparent substances. Carrying the curves into the infra-red, however, it is found that the effect soon reaches a maximum and then diminishes rapidly for still longer wave-lengths. Viewed as a whole, the curves resemble very strongly the type of dispersion curve we are accustomed to associate with transparent substances in a spectral region of strong absorption, and it may be that for these metals, *e. g.*, iron, nickel and cobalt, the visible spectrum is a region of similar abnormal properties.

There are a number of other magneto-optic phenomena—some of them requiring experimentation with films of metal less than one-millionth of an inch in thickness—which the writer and others have investigated. In general, however, it may be said that light, while unquestionably magnetic and electrical in nature, yields rather grudgingly to experiments attempting to probe this relationship, and one must frequently content himself with small effects. The explanation of this undoubtedly lies in the fact that the tiny electron whose activities not only give rise to light, but, moreover, determine or modify all the optical properties of bodies, executes its enormously rapid vibrations in magnetic fields of its own which are exceedingly large. To influence these vibrations by our gross experiments with fields which must, after all, be relatively small, is accordingly a difficult matter.